An Integrated Musculoskeletal Countermeasure Battery for Long-Duration Lunar Missions

Completed Technology Project (2007 - 2012)

Project Introduction

In the past year, we carried out a study to evaluate the effects of ab/adduction exercise on spine bone density and hip bone strength and density measured by quantitative computed tomography and finite element modeling. In 24 healthy subjects, we compared standard aRED lower body exercise, combined aRED, and ab/adduction and ab/adduction only, maintaining the same number of repetitions per group, in a 16 week study, with three exercise sessions per week. Eight subjects were assigned to each group. At the end of the study, two subjects had dropped out, leaving us with 8 subjects in the Ab/Add group, and 7 subjects each in the aRED and combined groups. The three groups showed differential responses of spine and hip bone density and hip bone strength to 16 weeks of training. The group of subjects doing aRED-like exercise consisting of squats and deadlifts showed robust increases in vertebral trabecular bone density (9% $p<0.05$), as well as smaller but statistically significant increases in femoral neck integral bone density, femoral neck cortical bone density, and femoral neck cortical volume. No changes were observed in the trochanteric region of the hip. No changes were observed in trabecular bone at any subregion of the hip. Using non-linear finite element modeling based on the quantitative computed tomography (QCT) images, we estimated changes of hip whole bone strength under simulated conditions of single-legged stance and a posterolateral fall. We observed that in the aRED-like group, there was a 9% increase in stance strength ($p<0.05$) but not in fall strength. The group of subjects carrying out abduction and adduction exercise showed no changes in any of the vertebral bone parameters. Abduction and adduction exercise resulted in changes in cortical bone parameters at the trochanter, with a 4.4% increase ($p<0.01$) in cortical bone volume, and a marginally insignificant 2.1% increase in the trochanteric compressive strength index, which integrates bone density and size to provide a measure of the resistance of the trochanter to compressive loading forces. Finite element computed strength in simulated fall loading resulted in a borderline insignificant trend ($p=0.15$) towards an increase (5.5%). The group doing combined exercise (half aRED-like and half abduction and adduction) showed no changes in any of the bone parameters. Thus, our study showed that standard aRED exercises consisting of squats, deadlifts, and heel raises have an osteogenic effect on the spine and to a lesser extent on the hip, focused on the femoral neck. While abductor and adductor exercise appears to have a modest osteogenic effect (cortical bone formation) on the trochanter of the hip, the failure of the combined group to show any changes indicates that any adbuctor/adductor exercise needs to be carried out in addition to the standard exercise protocol. The modest effects hint that the proper focus of the exercise could be functional mobility and strength rather than bone protection.

Anticipated Benefits

Outside of the space medicine community, there is a growing appreciation of

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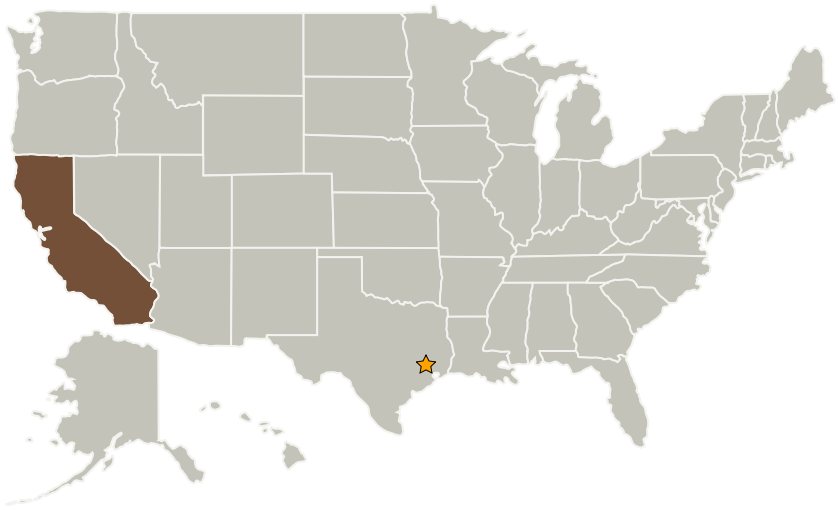
the importance of an integrated musculoskeletal approach towards prevention of age-related skeletal fractures. Hip fractures, which represent the most serious manifestation of osteoporosis, rarely occur without falls, and the exercise strategies developed here could potentially be adapted to an older demographic, with the same compact exercise and balance countermeasures geared towards reduction of falls and bone loss in the growing population of elderly. We believe that the compact characteristics of the combined countermeasure device (CCD), which are optimal for the spaceflight environment, will also fulfill the needs for an in-house exercise device or for a nursing home. It is well known that impaired balance is associated with aging and with an increased risk of falling. Balance training exercise in the elderly has been shown to reduce risk of falls. In particular, resistive exercise has been shown to increase muscle strength in the elderly, and increases in muscle strength and balance are associated with improvements in performance and mobility, which are important determinants of quality of life in the elderly. Finally, by focusing on resistive exercise in the abductor and adductor muscle groups, this device is expected both to improve lateral balance and reduce the rate of age-related bone loss by stressing those muscle groups that attach at the hip and thus provide significant mechanical loads on the proximal femur.

Primary U.S. Work Locations and Key Partners



Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Center / Facility:

Johnson Space Center (JSC)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

David K Baumann

Principal Investigator:

Thomas F Lang

Co-Investigators:

Jacob J Bloomberg
Carlos M Grodsinsky
Stuart M Lee
Barry A Spiering
Ajitkumar P Mulavara
Peter R Cavanagh
Jean D Sibonga

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Organizations Performing Work	Role	Type	Location
★Johnson Space Center(JSC)	Lead Organization	NASA Center	Houston, Texas
California State University-Fullerton	Supporting Organization	Academia	Fullerton, California
Universities Space Research Association Division of Life Sciences(USRA-DSLS)	Supporting Organization	Academia	Huntsville, Alabama
University of California-San Francisco	Supporting Organization	Academia	San Francisco, California
Wyle Integrated Science and Engineering Group	Supporting Organization	Industry	
ZIN Technologies Inc.	Supporting Organization	Industry Small Disadvantaged Business (SDB)	Middleburg Hts, Ohio

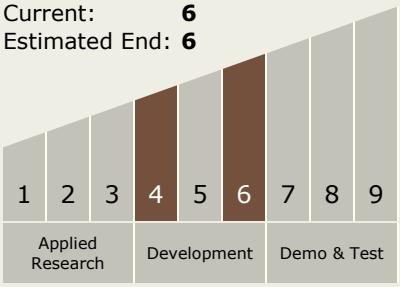
Primary U.S. Work Locations
California

Project Transitions

September 2007: Project Start

Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **6**



Technology Areas

Primary:

- TX06 Human Health, Life Support, and Habitation Systems
  - TX06.3 Human Health and Performance
    - TX06.3.2 Prevention and Countermeasures

Target Destinations

The Moon, Mars

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September 2012: Closed out

Closeout Summary: In the past year, we carried out a study to evaluate the effects of ab/adduction exercise on spine bone density and hip bone strength and density measured by quantitative computed tomography and finite element modeling. In 24 healthy subjects, we compared standard aRED lower body exercise, combined aRED, and ab/adduction and ab/adduction only, maintaining the same number of repetitions per group, in a 16 week study, with three exercise sessions per week. Eight subjects were assigned to each group. At the end of the study, two subjects had dropped out, leaving us with 8 subjects in the Ab/Add group, and 7 subjects each in the aRED and combined groups. The three groups showed differential responses of spine and hip bone density and hip bone strength to 16 weeks of training. The group of subjects doing aRED-like exercise consisting of squats and deadlifts showed robust increases in vertebral trabecular bone density (9% $p<0.05$), as well as smaller but statistically significant increases in femoral neck integral bone density, femoral neck cortical bone density, and femoral neck cortical volume. No changes were observed in the trochanteric region of the hip. No changes were observed in trabecular bone at any subregion of the hip. Using non-linear finite element modeling based on the quantitative computed tomography (QCT) images, we estimated changes of hip whole bone strength under simulated conditions of single-legged stance and a posterolateral fall. We observed that in the aRED-like group, there was a 9% increase in stance strength ($p<0.05$) but not in fall strength. The group of subjects carrying out abduction and adduction exercise showed no changes in any of the vertebral bone parameters. Abduction and adduction exercise resulted in changes in cortical bone parameters at the trochanter, with a 4.4% increase ($p<0.01$) in cortical bone volume, and a marginally insignificant 2.1% increase in the trochanteric compressive strength index, which integrates bone density and size to provide a measure of the resistance of the trochanter to compressive loading forces. Finite element computed strength in simulated fall loading resulted in a borderline insignificant trend ($p=0.15$) towards an increase (5.5%). The group doing combined exercise (half aRED-like and half ab duction and adduction) showed no changes in any of the bone parameters. Thus, our study showed that standard aRED exercises consisting of squats, deadlifts, and heel raises have an osteogenic effect on the spine and to a lesser extent on the hip, focused on the femoral neck. While abductor and adductor exercise appears to have a modest osteogenic effect (cortical bone formation) on the trochanter of the hip, the failure of the combined group to show any changes indicates that any adductor/adductor exercise needs to be carried out in addition to the standard exercise protocol. The modest effects hint that the proper focus of the exercise could be functional mobility and strength rather than bone protection.

Stories

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/8474)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/8476)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/8475)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/25199)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/8472)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/8473)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/25361)

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Project Website:

https://taskbook.nasaprs.com